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Analysis of Energy Efficiency from the Use of Heat-Reflective Window Screens in Different Regions of Russia and France

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Abstract

The article describes new energy saving windows with heat-reflecting screens, which significantly reduce heat loss. The study was based on the results of field tests performed on the windows with heat-reflective screens in a certified climate chamber. The method to determine the minimum indoor air temperature under standby heating using heat-reflective shields in the windows has been developed. Annual energy saving rate for the conditions of different regions of Russia and France was determined. Using windows with heat-reflecting screens results in a double power effect: reduced heat losses during the heating season due to increased window resistance; lower cost of heating buildings due to lowering of indoor ambient temperature.

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Keywords: windows with heat-reflective shields; setback heating mode; solar cells; relative humidity; energy saving; climatic conditions in France and Russia

1. Introduction

Pursuant to Russian legislation, annual specific consumption of energy in buildings as of 1 January 2020 shall be reduced by 40% of the basic level.

In France, the thermal regulations RT, which set reduction of energy consumption in buildings, were adopted. Annual energy consumption per 1 square meter of building Q [kWh / (m^2·year)] is the regulated value. The requirements of the Act Grenelle (Loi Grenelle), dated August 03, 2009 and the thermal regulation RT 2012 allowed to build buildings with low energy consumption (BBC, Q <50 kWh / (m^2·year) depending on region of France) with

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January 1, 2013 and with January 1, 2020 – only buildings with "positive energy» (Bâtiment à énergie positive, BEPos), i.e. with positive balance, such as the production of electricity (often due to photovoltaic method). Energy efficiency class "A" is assigned to such buildings.

Existing European and Russian energy efficiency regulations stipulate strict requirements regarding annual energy consumption, and particularly, the heat transfer resistance coefficient of translucent structures. Thus, European Union legislatures stipulate a coefficient of heat transfer resistance for windows by 2020 of 1,67-2,0 m^{2}·°C/W, while Russian official bodies stipulate 1,0-1,05 m^{2}·°C/W by 2016.

Consequently, the development of new designs of windows with high heat-shielding properties is an important task.

2. Development of the construction of windows with heat-reflective screen and their testing

The scientists from Ivanovo State Power Engineering University (ISPU) and National Institute of Applied Sciences in Strasbourg (INSA de Strasbourg) developed [1, 2] and patented [3-7] window designs with panel, roll and blinds type heat-reflecting screens, which are made of metal and significantly reduce heat losses. These constructions are shown in Fig. 1.

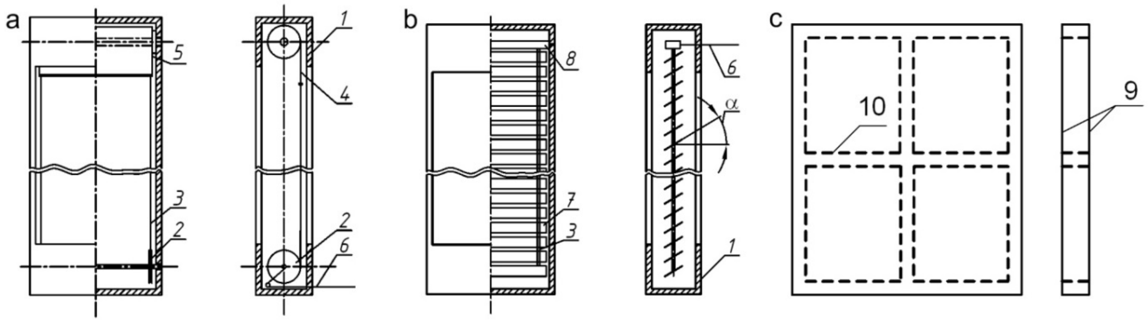

Fig.1. The design of the window block with roll (a), blinds (b) and double-panel (c) type heat-reflecting screen: 1 – the case; 2 – ribbed; 3 – directing; 4 – heat reflective screen; 5 – spring; 6 – a control cable, 7 – aluminum rotatable element; 8 – fixing; 9 – aluminum foil; 10 – distance planks; α – angle of inclination of the rotatable elements relative to the horizon.

Screens can be positioned indoors, outdoors or in a space between glass panes. The use of screens is desirable during nighttime or in the absence of people. Screens may be placed inside or outside buildings, or between window panes. The use of screens not only reduces losses related to heat transfer but also permits ambient temperature reduction in setback heating mode.

A certified environmental chamber belonging to “Ivanovostroiispytaniya” (an independent non-profit making organization engaged in construction engineering) was used [1, 2] to study the impact of using heat reflecting window screens on raising heat transfer resistance in windows and reducing heat losses. For control purposes, two double-glazed windows, made according to formula 4M1x10x4M1x10x4M1 and 4M1x10x4M1x10x4i, respectively, with low-emission coating, were used.

According to the given data (refer with Table 1), the use of low-emission I-glass increased heat transfer resistance from 0.47 $m^{2.0}$C/W to 0.61 $m^{2.0}$C/W (by 29 %), while adding a panel consisting of two metal screens positioned at a distance of 10 mm from each other on the cold side of the environmental chamber increased resistance to 1.76 $m^{2.0}$C/W (by 274% of control value 1, or 189 % of control value 2).

It should be noted that regarding the installation of metal shutters the maximum thermal resistance 0,813 m^{2} ^{0}C / W was obtained at $\alpha = + 90^{0}$, when the blinds completely block the window. This air gap inter-glass space was divided into two, reducing convective heat transfer component. The screen is reduced heat radiative component as each rotary element is made of aluminum with high heat reflecting capability.

Table 1. Results of tests on heat-reflecting screens in windows with low-emission coating.

Item	Heat flow, W/m^2	Inner glass temperature t_w, ^0C	Heat transfer resistance R, m^2*^0C/W
Control 1 4M1x10x4M1x10x4M1	76,1	12,5	0,47
Control 2 4M1x10x4M1x10x4i (coated)	58,9	14,15	0,61
2 cold side screens	20,77	18,65	1,76

3. Development of the method to determine the minimum indoor air temperature under standby heating

The current regulations (SP 60.13330.2012. “Heating, ventilation and air conditioning”) with reference to buildings during the cold season when not in use or during non-working hours permit reducing indoor ambient temperature below the regulation value, but not below 15 ^{0}C in residential buildings, 12 ^{0}C in public buildings and 5 ^{0}C in the case of industrial premises. In France, according to the regulations it is not allowed to decrease indoor ambient temperature below 16 ^{0}C for residential, public and administrative and service buildings.

Indoor temperature reduction in the setback heating mode creates a high energy saving potential [8-12]. Minimal ambient temperature in setback heating mode is to a large extent determined by the conditions necessary to prevent condensation on enclosing structure surfaces. We note the high probability of condensation on windows, because translucent structures are the weak spot in heat insulation of buildings.

It should be noted that the appearance of moisture on glass surfaces is not only an esthetic defect, as continuing condensation may eventually result in moistening of the structures [13, 14], with possible formation of fungi and mildew on window sills. Particular attention should be paid to horizontally positioned and slanting windows, also skylights, as pursuant to Current regulations (SP 50.13330.2012 “Buildings Heat Insulation”), the inner surface temperature should not be lower than indoor ambient dew-point temperature at the assumed outdoor ambient temperature during the cold season.

Relative humidity inside buildings RH is a regulated value (30 % to 65 % for public and residential buildings, 45 to 75 % for industrial buildings), while air humidity, window heat transfer resistance and outdoor ambient temperature are the factors determining dew-point temperature along internal glazing, and, therefore, the minimal ambient temperature (refer with Fig. 2) in setback heating mode (at a given heat transfer coefficient for inner window surfaces).

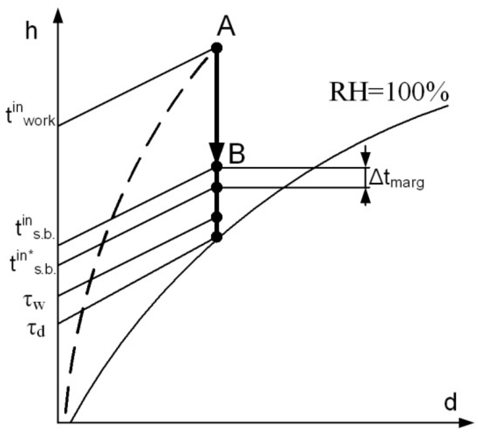

Fig 2. Determining ambient temperature in setback heating mode

As shown by calculations [2] and experimental data (refer to Table 1), the use of external heat-reflecting screens increases heat transfer resistance up to 1.76 $m^{2.0}C/W$ with a significant increase in internal glass temperature, thereby enabling us to further lower indoor ambient temperature (depending on indoor humidity) in the absence of people.

We were interested to know how to determine the value (refer with Fig. 2) to which an automated window control system may lower the ambient temperature in the setback heating mode while excluding condensation on internal window glass surfaces with enhanced heat insulation properties (using heat-reflecting screens).

In the course of mathematical transformations, it was deduced that minimal indoor ambient temperature in setback heating mode may be determined by:

$$t_{s.b}^{in} = \frac{\tau_d \cdot \alpha_{\text{in}} \cdot R_{\text{window}} - t_{out}}{\alpha_{\text{in}} \cdot R_{\text{window}} - 1} + \Delta t_{\text{marg}} \tag{1}$$

where τ_d - dew-point temperature at working hour ambient conditions, it can be determined by the Magnus-Tetens formula [15], ^0C;

Δt_{marg} - temperature margin for preventing condensation (assumed to be 1 ^0C);

t_{out} - outdoor ambient temperature, ^0C;

R_{window} - heat transfer resistance of window translucent area, $m^{2.0}C$ /W;

α_{in} - coefficient of heat transfer from indoor air to glass, assumed to be 8,7 W /$m^{2.0}C$.

Thus, knowing the window resistance value R_{window} during non-working hours, outdoor ambient temperature, ambient temperature and humidity during working hours we can determine minimal ambient temperature in setback heating mode.

In accordance with formulae obtained in Mathcad and Excel computing environments, we prepared a program for calculating the minimal ambient temperature in setback heating mode and using windows with the heat-reflecting screens. The results of these calculations may be seen in Fig. 3.

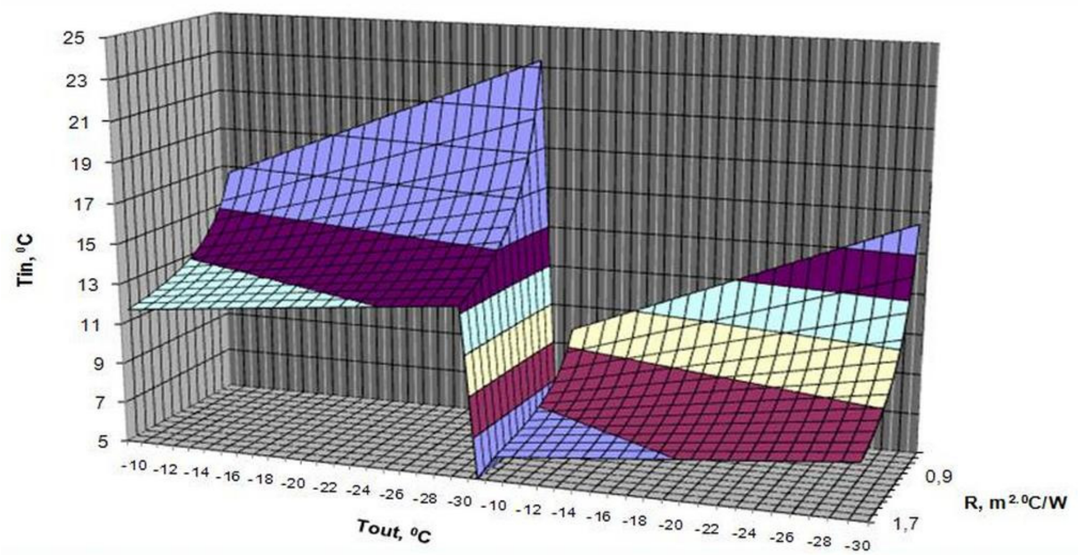

Fig. 3. Dependence of changes in minimal permissible ambient temperature tin in setback heating mode on R and tout., given RH=50 % in the left half of the graph and RH=35 % in the right half.

We simulated changes in the resistance of the translucent part of Window R from 0,5 to the resulting experimental value of 1,757 м^{2*0}C/W, while setting outdoor ambient temperature $t_н$ from – 10 to -30 ^{0}C, and ambient temperature during working hours at 20 ^{0}C. The calculation was made for relative humidity RH equal to 35 and 50%. As it is expected, the $t_{s.b.}^{in}$ will be significantly higher with higher indoor humidity. A significant difference also results from the use of screens. Thus, according to calculations, with relative humidity of 35%, outdoor ambient temperature of - 30^{0}C and the use of I-glass windows with two heat-reflecting screens, minimum permissible ambient temperature in setback heating mode falls from 16.4 ^{0}C to 7.8 ^{0}C, that is, by more than 8 ^{0}C, while with relative humidity of 50% the difference in temperature is more than 10 ^{0}C.

4. Determination of thermal energy saving for Russian and French regions

After processing data received from the Russian and French Meteorological Services, the authors determined the duration of daylight hours for each month in various cities of the Russian Federation. As it is well known, it is desirable to use screens at night and in the absence of people. Staff working hours are assumed to be from 8:00 up to 17:00.

Calculations were made for a window comprising a multiple heat reflecting I-glass unit (4M1x10x4M1x10x4I), using a panel screen consisting of two metal sheets separated by a low heat conductivity frame (Table 1). Design indoor temperature during working hours was assumed to be 20^{0}C, with relative humidity of 40%. For non-working hours (nighttime) in setback heating mode two levels of ambient temperature reduction were assumed – to standardized 12 ^{0}C (16 ^{0}C – for France), and to the minimal permissible ambient temperature satisfying the requirement of preventing condensation on translucent structures. Heat losses for the heating period were determined per 1 m^2 of window surface. Calculation data are given in Tables 2 and 3.

Table 2. Heat losses during the heating period per square metre of translucent structures, Gcal/m2

City	Check value, Q_k	Using setback heating mode ($t_{setback}$=12^{0}C and 16^{0}C), $Q_{setback\ (12/16)}$	Using a screen, $Q_{scr.}$	Using a screen in setback heating mode ($t_{(setback)}$=12^{0}C and 16^{0}C), $Q_{setback\ 12/16+scr}$	Using a screen in setback heating mode at lowered temperature, $Q_{setback\ (min)+scr}$
Norilsk	0,217	0,162	0,124	0,098	0,084
Moscow	0,154	0,112	0,096	0,075	0,062
Sochi	0,043	0,023	0,027	0,017	0,011
Strasbourg	0,111	0,088	0,057	0,049	0,028
Paris	0,099	0,076	0,051	0,042	0,025
Marseille	0,07	0,046	0,036	0,028	0,018

Table 3. Heat saving during the heating period per square metre of translucent structure, Gcal/m2/%

City	Using setback heating mode ($t_{setback}$=12^{0}C and 16^{0}C), $Q_{setback\ (12/16)}$	Using a screen, $Q_{scr.}$	Using a screen in setback heating mode ($t_{(setback)}$=12^{0}C and 16^{0}C), $Q_{setback\ 12/16+scr}$	Using a screen in setback heating mode at lowered temperature, $Q_{setback\ (min)+scr}$
Norilsk	0,055 / 25,4	0,093 / 43	0,119 / 55	0,133 / 62
Moscow	0,042 / 27	0,058 / 38	0,079 / 51,4	0,092 / 60
Sochi	0,02 / 45	0,016 / 37,2	0,026 / 60	0,032 / 74
Strasbourg	0,023 / 21	0,054 / 49	0,062 / 56	0,083 / 75
Paris	0,023 / 23	0,048 / 48	0,057 / 58	0,074 / 75
Marseille	0,024 / 34	0,034 / 49	0,042 / 60	0,052 / 74

Thus, the maximum thermal energy saving was achieved in all cities using panel heat reflecting screens and automation systems intended to maintain setback heating mode during non-working hours at the minimal permissible ambient temperature, and in the absence of condensation. Maximum saving (0,235 Gcal) was actually achieved for conditions in the city of Norilsk.

For the southern cities of Russia and most of French cities in the case of using these proposed energy-saving measures annual consumption of thermal energy for compensating transmission losses will be minimal (from 0,11 to 0,28 Gcal / m^2).

5. Conclusion

Using windows with heat-reflecting screens results in a double power effect: reduced heat losses during the heating season due to increased window resistance; lower cost of heating buildings due to lowering of indoor ambient temperature. The application for energy-efficient purposes is not only of heat-reflecting screens, automated heating systems using setback heating mode, heat recovery in exhaust air with the aid of regenerative heat exchangers [16, 17], but also of new designs and the results of research in the fields of "hybrid" ventilation, improved building air tightness and controlled fresh air supply depending on carbon dioxide levels in buildings has created a big energy-efficiency potential for systems supplying energy to both residential and industrial buildings.

Using the recommended window designs will help to achieve the energy consumption levels stipulated for buildings by Russian and European regulations [2].

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